

2/PRTS 1

DT09 Rec'd PCT/PTO 03 DEC 2007

A HEATER LINER FOR A PLASMA ETCHING REACTOR, AND AN
ETCHING METHOD USING THE LINER

TECHNICAL FIELD OF THE INVENTION

5 The present invention relates to plasma etching
reactors, and in particular the reactors used for
implementing micromachining or anisotropic etching
methods on a silicon substrate using a plasma by
implementing the alternating method described in document
10 US-A-5 501 893.

 During such an alternating method, steps of etching
a substrate with a fluorine-containing etching gas such
as SF_6 are alternated with surface passivation steps using
a plasma of a passivation gas C_xF_y , such as C_4F_8 , for
15 example.

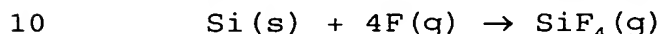
 The steps of the method are implemented under an
atmosphere at low pressure, enabling a plasma to be
established and maintained.

 During the step of etching with a plasma of
20 fluorine-containing etching gas, the substrate is
attacked isotropically by the atoms of fluorine. The
steps of passivation by means of a plasma of passivation
gas C_xF_y such as C_4F_8 enable a polymer film to be deposited
on all of the surfaces of the substrate that are exposed
25 to the plasma. Both the vertical surfaces and the
horizontal structures are thus covered. During the
following step of etching with a plasma of fluorine-
containing etching gas, and under the combined action of
vertical ion bombardment obtained by negatively biasing
30 the substrate, the polymer film is pulverized and removed
from the surfaces that are horizontal so that vertical
etching of the substrate can continue, whereas polymer
remains on the surfaces that are vertical so that the
polymer temporarily opposes the action of the plasma on
35 said vertical surfaces. Thus, by repeating the steps of
etching using a plasma of a fluorine-containing etching
gas in alternation with the steps of passivation using a

plasma of a passivation gas C_xF_y , it is possible to etch the substrate anisotropically.

The mechanism of etching the substrate by means of a plasma of fluorine-containing etching gas is as follows:

5 a plasma is generated containing electrons, ions such as SF_5^+ , and atoms of fluorine F. The atoms of fluorine reaching the surface of the substrate react chemically, e.g. when the substrate is made of silicon, in application of the following reaction:



The reaction products such as SiF_4 and the non-dissociated molecules of SF_6 , and also radicals S_xF_y remain in gaseous form and are removed by pumping.

During the step of passivating surface by means of a
15 plasma of passivation gas C_4F_8 , e.g. passivating surfaces of a silicon substrate, a plasma is generated containing electrons, ions, and radicals of the CF, CF_2 , ..., etc. type. These radicals or monomers bind to one another, thereby forming polymer chains $[-CF-]$ or $[-CF_2-]$. These
20 polymers condense on all of the surfaces exposed to the plasma and they cover those surfaces in a polymer film. These surfaces include not only the surface of the silicon substrate that is being etched, but all of the surfaces inside the reaction chamber.

25 During the following step of etching by means of a plasma of fluorine-containing etching gas, the surfaces subjected to ion bombardment under the effect of the negative bias have the polymer film removed therefrom. This applies in particular to the horizontal surfaces of
30 the silicon substrate, which can subsequently be etched by fluorine atoms F. This applies likewise to all of the surfaces other than those of the substrate that are subjected to the bombardment.

The problem with alternating methods of anisotropic
35 etching in accordance with US patent No. 5 501 893 is that the speed of etching decreases progressively over time, in substantially linear manner, as shown in

Figure 1. Thus, starting from a zero instant with an etching speed of 10 micrometers (μm) per minute, the speed diminishes progressively to reach 6 μm per minute after 12 hours (h) of operation, in an example of
5 operating a given reactor and under plasma generation conditions that are kept constant.

SUMMARY OF THE INVENTION

The object of the invention is to avoid such
10 negative drift in the etching performance of equipment for anisotropic etching of silicon using an alternating method of anisotropic etching in accordance with US patent No. 5 501 893.

The invention is the result of an in-depth analysis
15 of the phenomena that appear during the passivation and etching steps of the alternating method, leading to an explanation whereby this negative drift is due to the following process: during the passivation steps, all of the portions of the reaction chamber become progressively
20 covered in a film of polymer. This film is not removed during the etching steps when the surface of the reaction chamber are connected to a low potential, e.g. electrical ground. Because of the low potential, the corresponding receiver surfaces of the reaction chamber are not
25 subjected to ion bombardment, and they therefore conserve a polymer film similar to that covering the surfaces of the substrate that is to be etched. Over time, this film becomes thicker.

Although it is not subjected to ion bombardment, the
30 polymer film deposited on the receiver surfaces connected to ground potential is subjected to a small flux of ions and electrons of energy equal to $E = V_p - 0$ where V_p represents the positive plasma potential.

Generally, V_p is of ten-volt order, typically lying
35 in the range 15 volts (V) to 25 V relative to ground. This energy is not sufficient to eliminate the polymer film by pulverizing it, but it is sufficient to heat the

walls and thus the polymer film to temperatures of about 40°C to 60°C.

Initially, while the reactor is cold and clean, i.e. free from any polymer deposit of the $[-CF-]_n$ or $[-CF_2-]_n$ type, the speed at which silicon is etched is optimum in the sense that it is at its maximum. Thereafter, as the substrate continues to be etched, the polymer film condensed on the receiver surfaces of walls that are not subjected to deliberate ion bombardment grow and become thicker. Simultaneously, the film heats up under the effect of a flux of particles of energy V_p .

As it heats up, the film vaporizes partially and releases molecules of the C_xF_y type. Those molecules are in the gaseous phase and are therefore present in addition to the molecules of C_4F_8 that have been deliberately introduced by the mass flow meters. Thereafter, those molecules deposit on the surfaces of the substrate leading to an uncontrolled increase in the passivation of the horizontal surfaces of the silicon during the passivation steps. During the following etching steps, the excess passivation increases the time needed to destroy the polymer and start the process of etching the horizontal surfaces. This results in a reduction in the overall speed of etching.

The idea on which the invention is based is to act from the beginning, in an alternating method of etching, to prevent any formation of condensed deposits of polymer film on the receiver surfaces of the wall of the reaction chamber that are not subjected to ion bombardment, by raising the receiver surfaces to a temperature that is sufficient to ensure that any deposit of polymer that might occur thereon is volatilized.

Simultaneously, the invention seeks to implement this temperature rise without excessive expenditure of energy, and without any risk of injuring staff present in the vicinity of the reactors.

US patent No. 5 788 799 has already proposed reducing the formation of deposits on the walls of a deposition reactor by providing a heater liner of ceramic interposed between the plasma and certain portions of the reactor wall. The only methods described are deposition methods, and the ceramics selected comprise oxides, nitrides, or carbides of boron, aluminum, silicon, titanium, zirconium, or chromium.

The solutions described are not appropriate for an etching reactor, for various reasons, and in particular: contamination of the substrate to be etched, reduction in etching efficiency.

For this purpose, a plasma etching reactor of the invention comprising a reaction chamber surrounded by a leakproof wall, containing substrate support means, and communicating with a plasma source, further comprises a heater liner of an appropriate metal or alloy lining all or part of the leakproof wall of the reaction chamber in non-leakproof manner, and an intermediate thermal insulation space provided between the heater liner and the leakproof wall of the reaction chamber.

As a result, the heater liner presents a temperature higher than that produced solely by the plasma radiation, and the higher temperature of the heater liner reduces the quantity of polymer molecules deposited on the liner. Simultaneously, the heater liner itself constitutes the receiver surface, and forms a screen preventing polymers depositing on the leakproof wall, itself of the reaction chamber. The heater liner also presents a structure that avoids any contamination of the substrate to be etched and any reduction in the efficiency of the etching method.

In order to be compatible with an alternating etching method suitable for use in particular in the microelectronics industry for etching semiconductor substrates, the appropriate metal or alloy is preferably selected from metals or alloys that firstly do not react

with the fluorine-containing etching gas or the passivation gas to form volatile compounds, and secondly do not emit contaminating atoms under the effect of plasma bombardment. In particular, alkali metals, chromium, and heavy metals such as iron, copper, and zinc should be avoided. Good results can be obtained with a heater liner made of aluminum or of titanium, aluminum being preferred because of its low cost, and the ease with which it can be worked.

10 For an alternating etching method, the reactor of the invention may further comprise:

- bias means for biasing the substrate support means in order to control bombardment by particles coming from the plasma;

15 • an etching gas source, and means for controlling the etching flow rate to govern the introduction of etching gas into the plasma source;

- a passivation gas source, and means for controlling the passivation flow rate for governing the introduction of passivation gas into the plasma source;

20 and

- a control device adapted to cause the etching gas flow rate control means and the passivation gas flow rate control means to operate in alternation.

25 In an advantageous embodiment, the heater liner is fastened to the leakproof wall of the reaction chamber by a small number of fastening points.

Advantageously, the intermediate space between the heater liner and the leakproof wall of the reaction chamber communicate with the central space of the reaction chamber via an annular space of small thickness. The small thickness avoids plasma penetrating into the intermediate space.

30

Preferably, the fastening points are of thermally insulating structure opposing the transfer of heat energy by conduction from the heater liner to the leakproof wall of the reaction chamber.

35

The heater means of the heater liner may be of various types. In a first embodiment, the heater liner is thermally coupled to heater means such as electrical resistances suitable for connection to an external source of electrical energy.

By way of example, the electrical resistances may comprise thin-film electrical resistances and/or electrical resistances of the thermocoaxial type.

Alternatively, the heater liner is heated by radiant heater means such as infrared elements.

Preferably, the heater liner is associated with temperature-regulator means for regulating its temperature in a suitable range of temperature values.

In practice, the heater liner includes heater means suitable for heating it to a temperature higher than 150°C.

An additional problem of plasma etching reactors results from the presence of a conductive grid defining the reaction chamber downstream from the substrate support means. The purpose of the grid is to limit propagation of the plasma, and to confine it in the reaction chamber. The problem is that the grid tends to become clogged progressively, by accumulating particles of polymer.

The invention solves this problem by ensuring that the conductive grid is in thermal contact with the heater liner. It can be seen that the resulting rise in temperature of the grid avoids it becoming clogged and keeps it in a proper operating state for a long duration.

In addition, the presence of the heater liner in the reaction chamber produces an advantageous effect on the means for holding a substrate on the substrate support: an advantageous embodiment of such substrate support means comprises electrodes for attracting the substrate electrostatically. In known reactors, those electrodes become covered quite quickly in polymer, and their effectiveness decreases quickly over time.

The invention reduces this problem to a very great extent, since the electrostatic substrate-attractor electrodes remain sufficiently clean for proper operation of the electrodes over a long duration, apparently because the electrodes no longer become coated in polymer.

According to another aspect of the invention, a method is provided for etching a substrate by means of a plasma in a reactor as defined above, the method comprising alternating steps of etching the substrate by a plasma of a fluorine-containing etching gas, and steps of passivating surfaces by a plasma of C_xF_y passivation gas, and at least during the passivation steps, the heater liner is heated to a temperature higher than the condensation temperature of the polymers generated by the plasma.

In an advantageous implementation, the heater liner is heated continuously during all of the steps of the method.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, characteristics, and advantages of the present invention appear from the following description of particular embodiments, given with reference to the accompanying figures, in which:

- Figure 1 shows how etching speed varies in negative manner in prior art reactors;
- Figure 2 is a diagram of a reactor in an embodiment of the present invention; and
- Figure 3 is a plan view showing the bottom surface of the top wall of the heater liner.

DESCRIPTION OF PREFERRED EMBODIMENTS

In the embodiment shown in Figure 2, a plasma etching reactor comprises a reaction chamber 1 surrounded by a leakproof wall 2 containing substrate support means 3 and communicating with a plasma source 4.

The leakproof wall 2 of the reaction chamber 1 comprises, for example, a peripheral portion 2a which is connected to a front inlet portion 2b, itself open in order to communicate with an inlet tube 6 constituting the plasma source 4. The peripheral portion 2a and the front inlet portion 2b are made of metal, and advantageously connected to ground potential. The inlet tube 6 is made of dielectric material, and is surrounded by a coupling electrode 7 fed with alternating electrical current (AC) at radiofrequency (RF) by an RF generator 8.

A source 9a of etching gas and etching flow rate control means 9b such as a solenoid valve enable the delivery of etching gas to the end of the inlet tube into the plasma source 4 to be governed. Similarly, a passivation gas source 9c and means 9b for controlling passivation flow rate, e.g. a solenoid valve, serve to govern the delivery of passivation gas at the end of the inlet tube 6 into the plasma source 4. A control device 9e governs the etching flow rate control means 9b and the passivation flow rate control means 9c in alternating manner.

The coupling electrode 7 excites the gas in the inlet tube 6 to produce a plasma which then moves towards the inside of the reaction chamber 1 towards the substrate support means 3.

To control the bombardment by means of particles coming from the plasma, the substrate support means 3 are biased by an RF generator 11 to which they are connected by a bias line 10.

The reaction chamber 1 is connected via a pump line 12 to pump means 13 enabling a low and controlled gas pressure to be established and maintained inside the reaction chamber 1, which pressure is compatible with producing a plasma.

Downstream from the substrate support means 3, the reaction chamber 1 is defined by a conductive grid 5 also

connected to ground potential, with a mesh size that is associated with the ion density of the plasma.

The reactor of Figure 2 further comprises a heater liner 14 overlying the inside of all of the portions of the leakproof wall 2 that are at ground potential and in contact with the plasma. Thus, the heater liner 14 comprises a peripheral wall 14a which lines the peripheral portion 2a, and a top wall 14b which lines the front inlet portion 2b. The heater liner 14 is a wall made of an appropriate metal, itself connected to ground potential, and associated with heater means such as electrical resistances 17, or the like. Thermal insulation means are interposed between the heater liner 14 and the leakproof wall 2 of the reaction chamber 1.

In the embodiment shown, the thermal insulation means are constituted by an intermediate space 15 of appropriate thickness, e.g. of the order of about 0.5 millimeters (mm) to 1 mm, extending between the heater liner 14 and the leakproof wall 2 of the reaction chamber 1. Placed inside the reaction chamber 1, and in communication with the inside space of the reaction chamber via an annular space 14c of small thickness, e.g. having the same thickness as the intermediate space 15, the intermediate space 15 contains an atmosphere at very low pressure, and therefore presents good thermal insulation properties. Simultaneously, the heater liner 14 is fastened to the leakproof wall 2 of the reaction chamber 1 by a small number of fastening points, e.g. the three fastening points 16a, 16b, and 16c shown in Figures 2 and 3.

The fastening points 16a, 16b, and 16c are of a thermally insulating structure, further opposing the transfer of heat energy by conduction from the heater liner 14 to the leakproof wall 2 of the reaction chamber 1.

In the simple and effective embodiment shown in Figures 2 and 3, the heater liner 14 is suspended from

the leakproof wall 2 of the reaction chamber 1 by the fastening points 16a, 16b, and 16c each constituted by a projection having a head, extending beneath the face of the leakproof wall 2, and engaged in a respective slot 26a, 26b, or 26c in the top wall 14b of the heater liner 14. The slots 26a, 26b, and 26c are of the keyhole type having a wide portion for passing the head and a narrow portion for retaining the head, as shown in Figure 3.

Preferably, the inside surface 14d of the heater liner 14 is structured so as to present a low radiation emission coefficient. As a result, heating of a substrate 23 placed on the substrate support means 3 is limited, thereby avoiding any disturbance to the etching and passivation steps.

The electrical resistances 17 or the like or other means for heating the heater liner 14 are powered via a line 21 under the control of temperature regulator means comprising a control device 19 which receives information concerning the temperature of the heater liner 14 as picked up by a temperature sensor 18 and delivered over a line 20. The control device is designed to regulate the temperature of the heater liner 14 and to keep it within a range of temperature values that is appropriate for avoiding the deposition of $[-CF-]_n$ or $[-CF_2-]_n$ polymer molecules on the heater liner 14.

The temperature selected for the heater liner 14 may vary as a function of the type of C_xF_y gas used, and thus as a function of the type of polymer that is deposited during the passivation step.

In practice, the heater means 17 are adapted to heat the heater liner 14 to a temperature higher than 150°C , which is sufficient to avoid condensation of the polymers generated during the passivation step.

The conductive grid 5 is preferably in thermal contact with the heater liner 14 in a peripheral contact zone 22. As a result, the heating of the conductive grid 5 prevents it from becoming progressively clogged,

thereby considerably lengthening its useful lifetime. Heating the conductive grid 5 by specific heater means itself constitutes an independent invention that could be applied to reactors that do not include a heater liner

5 14.

Figure 2 is a diagram showing particular means for holding a substrate 23 on the substrate support means 3: these particular means are electrostatic electrodes 3a for attracting the substrate, and that attract the
10 substrate 23 by electrostatic attraction. Under such circumstances, it is necessary to maintain the electrostatic electrodes 3a in a satisfactory state of cleanliness, since otherwise the substrate 23 is not properly held by the substrate support means 3. Using
15 the heater liner 14 and means for heating it in satisfactory manner serves to reduce considerably the extent to which the electrostatic electrodes 3a becoming clogged, thereby likewise increasing the length of time during which the electrodes function properly for holding
20 the substrate 23 in satisfactory manner.

In operation, the pump means 12 and 13 maintain a suitable low gas pressure inside the reaction chamber 1. Appropriate gases are introduced for etching or passivation purposes via the gas generator means 9.
25 Powering the coupling electrode 7 from the RF generator 8 serves to generate a plasma 24 in the inlet tube 6, and the plasma 24 propagates into the reaction chamber 1 towards the substrate 23 because the substrate 23 is biased by the RF generator 11. Simultaneously, the
30 electrical resistances 17 powered by the line 21 and the control device 19 maintain the heater liner 14 at a suitable temperature for avoiding any passivation polymer depositing, and simultaneously protecting the leakproof wall 2 of the reaction chamber 1. As a result, at the
35 end of the passivation step, the monomer molecules are removed very quickly by the pump means 12 and 13, and introducing etching gas into the inlet tube 6 leads

quickly to an etching effect on the substrate 23 without the speed of etching being diminished progressively.

Thus, a method of etching the substrate 23 by means of a plasma 24 in a reactor having the above-described structure comprises alternating steps of etching the
5 substrate 23 by a plasma 24 of fluorine-containing etching gas and steps of passivating surfaces by means of a plasma 24 of C_xF_y passivation gas. During this method, the heater liner 14 is heated to a temperature higher
10 than the condensation temperature of the passivation polymer generated by the plasma, at least during the passivation step.

For simplification purposes, the heater liner 14 can be heated continuously throughout all of the steps of the
15 method.

Because of the thermal insulation means 15 interposed between the heater liner 14 and the leakproof wall 2 of the reaction chamber 1, the electrical power needed to maintain the heater liner 14 at the desired
20 temperature is restricted, and the leakproof wall 2 of the reaction chamber 1 is not heated pointlessly. As a result, the outside temperature of the leakproof wall 2 remains compatible with safety requirements, i.e. it is at a temperature that can be tolerated and staff in the
25 vicinity while the reactor is in use can touch its wall without running the risk of getting burnt.

The present invention is not limited to the embodiments described explicitly, but it includes the various variants and generalizations that are within the
30 competence of the person skilled in the art.